The Design of the Layer-0 Silicon Detector for the D-zero Experiment

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The D-zero experiment is constructing a single layer silicon microstrip detector (Layer-0) that will be installed inside the existing four layer silicon tracker in the second half of 2005. This new silicon detector layer consists of 48 pieces of radiation hard silicon sensors mounted on a very stiff low mass carbon fiber composite structure. The sensors are 320 μm thick and single sided. A new beryllium beam tube with a diameter smaller than the current beam tube will be installed. The major driving factor for the design of this new silicon layer is the extremely tight space constrain. This new silicon layer must fit between the beam tube flanges that have an outer radius of 15.24 mm and the existing silicon tracker with an accessible inner radius of 22.02 mm. The Layer-0 sensors will be subject to a radiation level equivalent to about 10^{14} one MeV neutrons per square cm over its expected lifetime.

The motivation of this new addition to the D-zero silicon tracker is to provide more robust tracking and pattern recognition for higher luminosity operations. This new layer-0 will mitigate tracking losses due to radiation damage and failure of the existing silicon tracker. It is expected that the inner most layer of the current silicon tracker will begin to fail at the exposure of approximately 3.5 fb^{-1} due to radiation damage. The addition of the layer-0 can also improve the physics reach. It is expected that with the layer-0, the impact parameter resolution can be improved by a factor of two and the b-tagging efficiency by 20% that will be important for resolving the B_s flavor oscillation.

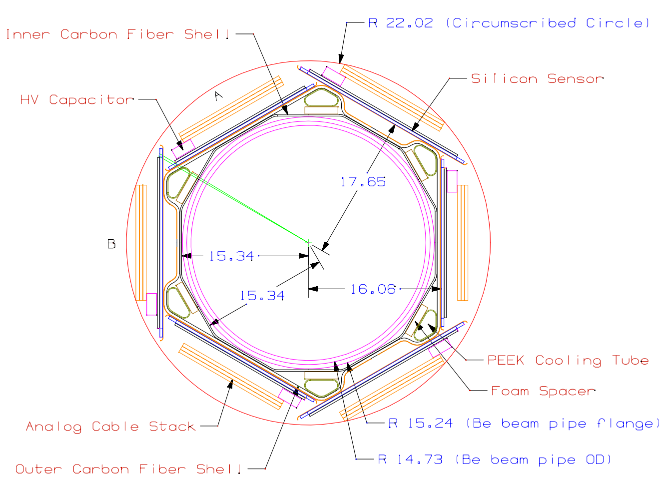

Fig. 1. Cross-sectional view of the Layer-0 sensor region.

A cross-sectional view of the Layer-0 detector sensor region is shown in Fig. 1. The Layer-0 has a six-fold crenellated design that fits in the available space while maximizing the azimuth coverage. The active region of Layer-0 is divided into 8 sections with a total length of approximately 760 mm. The parameter of the sensors is summarized in Table 1. The 7 cm long sensors labeled as A and B types populate the four central sections. The 12 cm long sensors labeled as C and D types are placed in the four outer sections (two sections on each side). The A and C type sensors with smaller pitch are placed closer to the beam and the B and D types with larger pitches are slightly farther away from the beam center. Each sensor has 256 signal strips.

Table 1. Parameters of the Layer-0 Silicon Sensors

Parameter	**A**	**B**	**C**	**D**
Detector length (mm)	7	7	12	12
Strip pitch (μm)	71	81	71	81
Active width (mm)	18.18	20.74	18.18	20.74
Inner radius (mm)	16.10	17.60	16.10	17.60
Max angle (radians)	0.51	0.53	0.51	0.53

There are a total of 48 pieces of hybrid electronics circuits. Each hybrid has two SVX4 readout chips. The hybrids are mounted at the two ends of the structure on two separate hexagonal shells. The signals from the silicon sensors are transported to hybrid circuits by analog cables.

The silicon sensors are supported by a novel carbon fiber composite structure that is stiff and low mass. The inner diameter of the Layer-0 structure is determined by the size of the beam tube and its flanges. A 1.16” mm diameter new beryllium beam tube will replace the current 1.5” diameter beam tube. The new beam tube has a wall thickness of 0.50 mm and is procured from Brush-Wellman Electrofusion. The entire Layer-0 structure must be able to slide over the new beam tube and its flanges that have a diameter of 15.24 mm.

The mechanical support structure for the Layer-0 consists of a 12 sided thin cylinder that is 1672 mm in length and four shorter sections of hexagonal shaped shells that are bonded to the long cylinder. The long cylinder and the four shells are made from high modulus carbon fiber composite material. Two of the hexagonal shells located in the middle section of the structure support the silicon sensors and the other two shells located near two ends of the structure support the hybrid circuits. The silicon sensors and the hybrid circuits are glued to the surface of the hexagonal shells.

The cooling for the sensor and electronics is an integrated part of the mechanical design. The six cooling tubes made of high strength thin wall PEEK are glued in the 6 openings between the hexagonal shells and the 12 sided long support cylinder as shown in Fig. 1. Two manifolds terminating the PEEK tubing are located at the two ends of the long cylinder. These manifolds are manufactured also from a carbon fiber composite material. The heat generated by the Layer-0 detector is mainly from the 96 pieces of SVX4 chips. Each chip can generate up to 0.5 W of heat.

The Layer-0 sensors must be cooled to a temperature below about $-10\ ^{o}$C in order to withstand the radiation exposure over their expected lifetime. The coolant we plan to use for Layer-0 is a mixture of water and ethylene glycol. A new cooling system capable for low temperature operation will be constructed to provide adequate coolant flow through the long PEEK tubing. The coolant that flows through the silicon detector is kept at sub-atmospheric pressure in order to prevent catastrophic leaks. The existing dry gas system will be used to flow of dry gas to the Layer-0 in order to avoid water condensation on the cold surfaces.

The 12 sided long cylinder and the four hexagonal shaped shells are constructed from the Mitsubishi K13C2U carbon fiber prepreg. The nominal thickness of the prepreg is 0.075 μm. The long cylinder is made of three Layers of prepreg with a $0^{o}/90^{o}/0^{o}$ arrangement. In another words, fibers are along the long axis in the two outside layers and are in the azimuth direction in the middle layer. Its cured thickness is 195 μm. The four hexagonal shells are made of 5 layers of the same prepreg with a fiber $+20^{o}/-20^{o}/0^{o}/-20^{o}/+20^{o}$ orientation and the cured thickness is 325 μm. Compared to the 90^{o} fiber arrangement, much sharper corners of the shell can be constructed with the $\pm 20^{o}$ arrangement using high modulus fibers. A special construction technique was developed to make these difficult structures. The prototype parts we made have excellent mechanical accuracy and surface quality. Our design has also achieved good stiffness for such a long and thin structure. The Layer-0 structure is connected at the two ends to the mechanical structure of the existing silicon tracker via a precision mounting system. The ANSYS analysis shows that the fully loaded long structure only sags by 32 μm in the middle.

The 48 pieces of silicon sensors can be divided into four groups according to their length (70 and 120 mm) and pitch (71 μm and 81 μm) as shown in Table 1. The sensors are manufactured by Hamamatsu using a radiation hard process. The readout electronics are based on SVX4 ASIC co-developed by Fermilab, LBL and Padova. Signals from the sensors will be brought to the readout chips by using specially designed fine pitch analog cables made by Dyconex., Zurich. The pitch of the 16 μm wide traces on the 50 μm thick kapton cable is 91 μm. Two pieces of such cables, one on top of the other are required to readout one sensor. The two pieces of cable are offset laterally by 45.5 μm to have a 45.5 μm effective pitch that matches the pitch of the SVX4 chips. Special adaptors glued to the ends of the sensors will be used to match the 45.5 μm effective pitch of the cables to the 71 μm and 81 μm pitch of the signal strips on the sensor. The traces on the cables are wire bonded to the traces on the pitch adaptors and the hybrid circuits.

A specially designed grounding scheme [1] is developed to combat the coherent noise pickup by the sensors and by the analog cables that are mounted on a structure made of highly conductive graphite fibers and are very close to the beryllium beam tube. The graphite fiber embedded in the epoxy cannot be tied to ground easily. An electric shielding layer consisting of a fine copper mesh on a 25 μm thick kapton is co-bonded on the surface of the four hexagonal shells. The copper mesh is connected to the system ground.

An isometric view of the Layer-0 support structure is shown in Fig. 2. Only one half of the entire structure is shown in this figure. The left section is for sensor mounting and the right section is for hybrid support. The black colored section on the right side that is not covered by the copper mesh layer is just a mechanical extension in order to reach the locations where the structure can be supported. The cooling manifolds are mounted at the two extreme end of the structure.

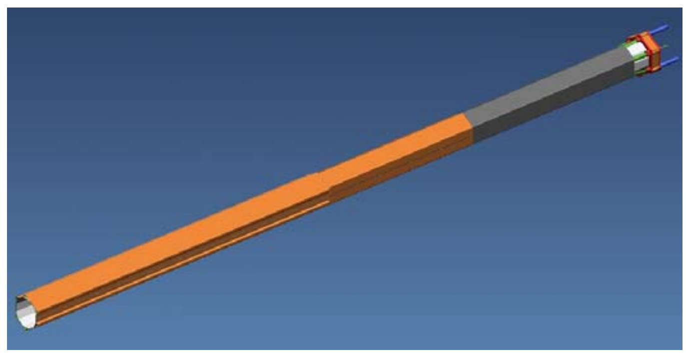

Fig. 2. One half of the carbon fiber composite structure.

REFRENCES

[1] M. Johnson, "A Silicon Detector System on Carbon Fiber Support at Small Radius," IEEE Nuclear Science Symposiuim, Oct. 2003, Portland, Oregon.